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# Integrating climate change vulnerability assessments from species distribution models and trait-based approaches

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ABSTRACT

To accommodate climate-driven changes in biological communities, conservation plans are increasingly making use of models to predict species' responses to climate change. To date, species distribution models have been the most commonly used approach for assessing species' vulnerability to climate change. Biological trait-based approaches, which have emerged recently, and which include consideration of species' sensitivity and adaptive capacity, provide alternative and potentially conflicting vulnerability assessments and present conservation practitioners and planners with difficult choices. Here we discuss the differing objectives and strengths of the approaches, and provide guidance to conservation practitioners for their application. We outline an integrative methodological framework for assessing climate change impacts on species that uses both traditional species distribution modelling approaches and biological trait-based assessments. We show how these models can be used conceptually as inputs to guide conservation monitoring and planning.



## 1. Introduction

Biodiversity loss is occurring across much of the world (Butchart et al., 2010; Secretariat of the CBD, 2010; WWF, 2012) and anthropogenic climate change has been identified as one of the main drivers of these trends (Parmesan and Yohe, 2003). This threat is predicted to become more severe over the next century owing to accelerating global warming, and changes in precipitation patterns and timings, as well as alterations in climatic extremes (IPCC, 2007). Various predictions have been made of the impacts of climate change on the world's habitats and species, generally indicating that more species will become threatened with extinction, and that their distributions will move substantially, often shrinking (Sala et al., 2000; Midgley et al., 2002; Thomas et al., 2004; Bagchi et al., 2013). Climate change is not only additional to other direct threats to biodiversity, such as land-use change, over-hunting, and invasive species, but can also act synergistically with these threats (e.g. Benning et al., 2002; Hof et al., 2011). There is, therefore, an urgent need to assess the potential consequences of future climate change on species, and to initiate adaptive management planning that helps shape current and future conservation decisions. The need to produce adaptive management plans has stimulated considerable research in recent years, resulting in various approaches to assessing climate change-driven risks

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(Game et al., 2011; Hole et al., 2011; Gardali et al., 2012; Bagchi et al., 2013; Foden et al., 2013; Garcia et al., 2014).

To date, the majority of climate change vulnerability assessments have used Species Distribution Models (SDMs), which correlate data on species' contemporary distributions with observations of recent climates and then apply these correlations to climate projections to predict the location(s) of suitable climatic conditions for a species in the future (e.g. Beaumont and Hughes, 2002; Harrison et al., 2006; Phillips et al., 2006; Huntley et al., 2008; Jensen et al., 2008). Consequently, in predicting species responses to projected future climate change, SDMs use future exposure of a species to climate change (i.e. the extent to which the species' physical environment will change) to climate change as an input parameter and assess the sensitivity of the species (the potential for the species to persist, *in situ* or elsewhere) to that change. However, such SDMs take no account of the potential capacities of species to adapt to such changes by dispersal, behavioural change or evolutionary adaptation. For example, a species might have ample climatically-suitable habitat in the future, but its inherent dispersal limitations may make reaching this habitat unlikely. The shortcomings of using basic SDM approaches to simulate future species changes are well recognised (see Seo et al., 2009; Wiens et al., 2009; Sinclair et al., 2010), and include their lack of consideration of biological information about the likelihood of species realising distribution changes projected by SDMs (Pearson and Dawson, 2003). This shortcoming has led to the development of next-generation, dynamic (or process-based) SDMs that include relevant biological traits such as dispersal ability, habitat requirements and other key parameters to assess the likelihood of population changes being realised over space and time (Kearney and Porter, 2009; Conlisk et al., 2013). However, to parameterise such models requires quantitative data for a species or system; something that is lacking for many species. An alternative approach, which we term 'Trait-based Vulnerability Assessment' (TVA) considers the vulnerability of species to potential climate change based on the best available current knowledge of the species' ecology and life history. Unlike process-based models, TVAs use composite indices (as opposed to modelling) to characterise the vulnerability of species to climate change.

TVA approaches identify, for a species, the traits that are known or presumed to render it vulnerable to climate change impacts. This often entails consideration of three aspects of vulnerability: exposure to climate change, sensitivity to changes in climate, and capacity to adapt to such changes, with the latter two aspects benefiting from the consideration of traits. Species that combine high exposure, a high degree of sensitivity, and low capacity to adapt will be most vulnerable to climate change. These methods provide a relatively rapid approach to score species according to their likely vulnerability to future climate change (Rowland et al., 2011). Several variants on the TVA approach have recently been developed, and are being applied to increasing numbers of taxa (Williams et al., 2008; Chin et al., 2010; Dawson et al., 2011; Graham et al., 2011; Thomas et al., 2011; Young et al., 2011; Foden et al., 2013).

To date, however, there have been few explicit comparisons of SDMs and TVAs in terms of their objectives, the conceptual frameworks underpinning them (Rowland et al., 2011; Pacifici et al., 2015), and the results they produce (Garcia et al., 2014). Furthermore, little attempt has been made to demonstrate how their outputs can be applied at scales relevant for conservation decision making (national and smaller). We seek to address remaining gaps of these two approaches by considering how elements of each could be used to strengthen the other, and propose how they can be integrated to provide improved climate change vulnerability assessments. Our resultant framework also indicates how both approaches can feed into adaptive management planning and spatial conservation prioritisation at scales where conservation decisions are made (Margules and Pressey, 2000; Moilanen et al., 2009; Ladle et al., 2011). We also outline some of the challenges in using the results of climate change vulnerability assessments within the framework of systematic conservation planning.

## 2. Species Distribution Models (SDMs)

SDMs, in their most basic form, correlate data on the distribution of a taxon (typically a species) with data on contemporary climates (relating to the same time period from which the distribution data were derived) to establish a relationship between climate and species occurrence. Resultant models (or more commonly suites of models) are then applied to future climate change projections to produce forecasts of species' potential future ranges. Such SDMs have been applied to species at scales ranging from global (Thomas et al., 2004) and continental (Garcia et al., 2012) to regional (Thuiller et al., 2005), and have been used to assess projected turnover of species in key sites or protected areas (Hole et al., 2009, 2011; Araújo et al., 2011; Bagchi et al., 2013). Such models are most often used to indicate climate change vulnerability by comparing the projected change in range size and location between the present and a future period (often under various scenarios of dispersal), or even the change in coverage by key sites or protected areas under future climate change (Coetzee et al., 2009; Bagchi et al., 2013).

However, there are a myriad of biotic and abiotic factors that limit the use of such projections for assessing species' climate change vulnerability; a consequence of the fact that such models aim principally to assess geographical shifts in climate suitability rather than species vulnerability *per se*. Such correlative models generally fail to reflect differences between species in terms of their biology (e.g. dispersal ability, tolerance of habitat degradation, demography and the way that species interact with one another), to incorporate population dynamics and information on current and projected land cover, or to account for the discrepancy between climatic preferences as inferred from species' realised geographical distributions and their fundamental climatic niches as determined by their physiology (e.g. Araújo et al., 2013; Khaliq et al., 2014). In addition, they often cannot be used for species with small geographic distributions or for which only few records are available (Williams et al., 2009), despite such species often being those of greatest conservation concern. Nonetheless, SDMs can provide useful preliminary indications of the potential spatial and temporal patterns of change in species abundance, distribution and community composition (Elith et al., 2006; Gregory et al., 2009).

## 3. Trait-based Vulnerability Assessments (TVAs)

TVAs aim to combine indices or scores for exposure to climate change and species-specific combinations of biological characteristics that may increase or decrease the effects of climate changes on a species, in order to gain some overall measure of vulnerability (Williams et al., 2008; Young et al., 2011; Gardali et al., 2012; Foden et al., 2013). They quantify exposure in a variety of ways, though these are typically simple, uniformly applied measures of change in climatic variables that are presumed or demonstrated to be relevant. These assessments consider intrinsic sensitivity and adaptive capacity but sometimes also add extrinsic factors that might influence a species' capacity to adapt (e.g. prevention of dispersal due to species-specific habitat barriers). In general, TVAs assume that vulnerability to climate change is a product of three components. Like SDMs they consider exposure and sensitivity, although sensitivity assessments in TVAs usually consider factors